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(54) COMPUTER CONTROL OF FLOTATION METALLURGY

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The present invention relates to the computer control of flotation processes wherein reagent inputs to the flotation cell are mathematically correlated with the weight of ore feed and control of the concentrate and tailing streams is maintained by adjusting the pulp level of the cell depending upon the comparison between the streams composition and the set values therefor.

The present invention relates to flotation separating systems and, more particularly, to the control of the flotation system process.

It is well known that flotation is used in industry for the separation of minerals from their ores. Basically, the mineral to be recovered is selectively floated from the other ore components and is separated into a concentrate stream for further refining. The other constituents of the ore, e.g., rock, etc., are collected in a tailing stream which is routinely disposed of as waste material. The flotation process requires both the use of various reagents, e.g., collectors, frothers, activators, depressants, etc., to produce the desired separation characteristics, and the careful control of numerous process variable to achieve optimum separation efficiencies and mineral recoveries.

As in all separation processes, the desired result is to achieve the highest mineral recoveries at the lowest operating costs. Operating costs such as, reagents, power requirements, manpower efficiency, etc., must all be minimized for the process to be economically feasible. Additionally, and equally important, since the flotation process is an integral part of the total milling and smelting operation, it is essential that the concentrate and tailing streams be maintained within proper operating ranges to minimize process fluctuations. Ore feed streams do not lend themselves to a steady-state operation due to normal variations in the ore mix being treated and the flotation process variables must be controlled so as to compensate for variations in the feed and yield a concentrate within the desired operating range while minimizing losses of valuable mineral in the tailing.

An operator manually controlling a flotation process normally adjusts the addition rate of collector, frother, activators or depressants, and possibly froth modifiers along with infrequent change in cell pulp level to achieve the best control he can. Because of this complex interaction of changes in these parameters with resulting change in the concentrate and tailing grades, the control of the process has remained an "art" and requires a long period to train an effective operator.

With the advent of on-stream analytical devices it is hoped that a more systematic automatic control method can be developed to eliminate operator "error" and improve the response time to changes in other characteristics which cause deviation from the desired results.

U.S. Patent 3,551,897 granted to H.R. Cooper for example, claims a rather complicated method for continually adjusting operating conditions in a flotation plant to determine the optimum economic operating conditions. Small changes in the operating parameters of feed rate, lime, collector,frother, tailing withdrawal rate, and thickness of the froth layer are continually made; the operation of the flotation plant measured, and an economic index of the operation calculated. The levels of all these operating variables resulting in optimum performance are thus selected. The problem with this proposed control is that all of the operating variables are interrelated, and to determine the value of the co-efficients used to control the individual operating parameters requires a large number of changes in the individual parameters to establish the optimum choice of the operating parameters. It would appear that a simple but effective computer-controlled method for operating a flotation plant would be desirable and beneficial.

What we have discovered is that with fixed reagent additions, i.e., proportioned to the tonnage of ore being treated, that steady concentrate and tailing grades can be effectively maintained by simple automatic cell level control as herein described.

The target concentrate grade and tailings may be chosen to optimize mill performance within the operating constraints such as ore availability and external constraints such as the concentrate grade desired for further treatment, normally smelting.

It is an object of the present invention to provide an improved method for the process control of flotation separating systems.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawing in which: Figure 1 is a schematic diagram of a preferred embodiment of the invention; and Figure 2 is a time chart showing the improvement in operational consistency in accordance with the invention as compared to manual operation.

Generally speaking, the present invention contemplates the computer control of flotation processes wherein reagent inputs to the flotation cell are mathematically correlated with the weight of ore feed and control of the concentrate and tailing streams is maintained by adjusting the pulp level of the cell depending upon the comparison between the streams composition and the set values therefor. Froth height in the cell is not controlled directly in the process since, among other factors, the froth height is found to vary depending upon the material being processed and the flotation reagent being added. The process control contemplated herein allows for wide variations in feed compositions while not adversely affecting process efficiency, a very significant problem for manual control systems.

In carrying the invention into practice, it is preferred to employ a flotation circuit consisting of 4 flotation cells in series, said circuit producing two concentrate streams and a tailing stream. Magnetic separators may also be included for ores containing magnetic pyrrhotite. Referring to the cells in the flow direction as a, b, c and d, the froth from cells a and b are combined to form the primary concentrate stream and the froth from cells c and d are combined with the magnetic fraction stream from the magnetic separator to form the secondary concentrate stream. The tailing stream is the pulp from the last cell in the series, cell d. Control of the flotation process is achieved by a feed-forward reagent control based on the weight of the ore feed and by a feedback control of metallurgy by cell pulp level adjustment. The signals from the sensing devices are transmitted to the computer and applied to a control equation of the process to calculate the preferred operating conditions. The control of metallurgy by cell pulp level adjustment is achieved by maintaining the primary concentrate grade from cells a and b and the tailing grade from cell d within specified ranges. No restrictions are imposed upon the secondary concentrate stream.

Referring now to Figure 1 which will be described as applied to complex nickel bearing sulfide ore, containing pyrrhotite, pentlandite and chalcopyrite as the principal mineral species and having a nickel content of approximately 1.2%, the operation and control of the flotation circuit contemplated herein to produce two concentrates and a tailing stream can be shown. The ore feed 11 consists of crushed and ground ore having a particle size in the range of approximately 85% minus 65 to plus 325 mesh. The ore feed 11 is fed into

magnetic separator 12 wherein a large proportion of iron sulfide (pyrrhotite) is separated as stream 13 and the remainder of the feed 11 as flotation feed 14a. The weight of ore feed 11 is sensed by weightometer device 29 which generates an input signal to the computer 30. A simple equation correlating the reagent flows to the flotation cells to the weight of ore feed 11 is stored in the computer and calculates the appropriate impulse signals for each of the reagents and cells and transmits the signal to reagent valves, 16a, 16b, 16c and 16d. It has been found that an input signal to the computer 30 about every 3 minutes is suitable for proper reagent control of the flotation circuit, and, if a change in the weight flow is detected, new reagent flows are calculated and impulse signals to reagent valves 16a, 16b, 16c and 16d generated. As will be appreciated by those skilled in the art, the simple equation representing the reagent flow in terms of ore feed weight may be modified, e.g., distribution ratios, to take into account specific operating problems.

As an example of a preferred embodiment of the invention, Table I describes the distribution of reagents in the flotation circuit.

TABLE I

Reagent	Cells (15)
Xanthate	a, b, c
Frother	a, c, d
Copper Sulfate	a, b, c

Flotation feed 14a is fed into flotation cell 15a wherein froth 19 and pulp 14b are separated. Pulp 14b is then the feed for cell 15b wherein froth 20 and pulp 14c are separated. A similar cascade process is shown for cells 15c

and 15d. Froth 19 and froth 20 are combined to form the primary concentrate stream 21 which is analyzed by sensing device 27. Sensing device 27 provides input signals to the computer 30 responsive to the composition of the primary concentrate stream 21. Sensing device 28 performs a similar function for tailing stream 26. As can be seen from Figure 1, froth 22 and froth 23 are combined to form stream 24 which is combined with stream 13 forming the secondary concentrate stream 25. Sensing devices 27 and 28 are on on-stream analyzers, such as an X-Ray fluoresence (XRF) analyzer, and the input signals to the computer 30 are mathematically correlated by a program stored in computer 30 which generates impulse signals to pulp level valves 18a, 18b, 18c and 18d. The pulp level valves may be of the dart plug type and may be conveniently located in the tail box of each cell. Sensing devices 17a, 17b, 17c and 17d provide input signals to the computer 30 indicating the current pulp level of the respective cells.

The on-stream analyzer devices 27 and 28 are essential for proper process control and they must be reliable both in operating time and assay quality. As an example of a preferred method, samples are taken for both continuous on-line analysis and to provide daily composites for wet chemical analysis. All pulp samples are cut by automatic cutters with the timing cycle set to give a sample flow of approximately 8 gallons per minute. The samples are pumped to a central location containing the analyzer. In the analyzer room a gang sampler cuts all streams every 15 minutes for the composite sample which is collected on vacuum filters. The remainder of the sample is split in a splitter box, with 6 gallons per minute being rejected to the plant and 2 gallons per minute presented to the XRF analyzer sample cell.

The analyzer is a 15-stream capacity Applied Research Laboratories unit which is under the control of the computer. This unit has a fixed position end on X-Ray tube and the sample cells are mounted on a moving horizontal rack. Analyses for elements such as Cu, Ni, Fe, S and Si can be carried out on a maximum of 11 slurry streams per run. Linear regression equations are used to calculate assays taking into account interelement and slurry density effects. The results are printed out both in the analyzer room and the control room every 6 to 12 minutes depending on the number of streams analyzed. As will be appreciated by those skilled in the art, wet chemical analyses of process streams is extremely accurate and results over a long period of time show analytical variations of only 7% to 12% (depending on the sample and element determined) with the on-stream XRF analyzer; a variation well within acceptable operating performance.

A satisfactory flotation circuit process control has been found to be achieved by controlling the pulp level of cells 15a and 15b by the composition of the primary concentrate stream 21 and by maintaining the pulp levels of cells 15c and 15d by the composition of tailing stream 26. Thus, for example, input signals from sensing device 27 are transmitted to the computer 30 about every 3 minutes and the computer compares the values with the grade targets stored in computer 30. Based on the comparison, the computer 30 calculates the desired pulp levels for cells 15a and 15b and transmits appropriate signals to valves 18a and 18b. Similarly, the control logic of cells 15c and 15d is maintained by signals activating valves 18c and 18d. In order to develop a control equation, the sensitivity of grade concentration to cell level change had

to be determined. A transient response study showed that a change of about 20% in the cell level caused a substantial change of about 3.5% in the concentrate nickel grade and about 0.025% in the tailing nickel grade. Fast responses to cell level changes for both the concentrate and tailing streams were obtained indicating that this particular flotation process consisting of 4 cells will provide satisfactory process control characteristics. As will be appreciated by those skilled in the art, other flotation design circuits exhibiting similar characteristics may also be suitably employed. Since the sensitivity of the tailing stream is much less than the concentrate stream some problems could be experienced in controlling the tailing grade. The process control equation for maintaining the cell pulp level has been designed with both proportional and integral gain coefficients and represents a feedback control design; other suitable process control techniques may also be employed. The following equation represents a typical control equation contemplated herein:

$$L = K_g(Xn - Xn\text{-}1) + K_gI\ (Xn - Xsp)$$

where L is change in Cell pulp level at ^{nth} sampling interval; L being measured as the percentage of the full scale range of the cell level control device

Xn is grade at ^{nth} sampling interval

Xsp is grade target

K_g, I are proportional and integral gains, respectively

Kg = 0 - 10

I = 0.1 - 20

To demonstrate the application of the above equation to the process the computer checks every three minutes to determine if there is a new and valid concentrate assay. If there is, it will then compare with the grade target. This target is entered or changed as required by the operators. Based on the comparison, the computer will calculate new cell level targets using the equation. Thus, if the concentrate nickel grade is lower than the target, the computer will generate impulse signals to lower pulp levels and if the concentrate grade is higher than the target, the computer will generate impulse signals to raise pulp levels.

The control logic of cells c and d to meet a tailings grade target is similar to that of cells a and b. The only difference is that an alert message is printed when the maximum or minimum cell levels are reached and targets cannot be maintained. To correct for this situation the operator can change the concentrate target or manipulate the reagent distribution ratio. As will be shown hereinbelow, the computer was able to maintain the concentrate grade at or near the specified target more consistently than the tailing stream and with a minimum fluctuation.

Referring now to Figure 2, the time chart shows the nickel level of the primary concentrate stream 21 and the tailing stream 26 of the flotation circuit, as described hereinabove in Figure 1, for a typical production period of 24 hours. Computer control of the process as contemplated herein (using values of Kg and I of 0.5 and 1.8, respectively, in the above described control equation) was compared with manual control of the process, wherein adjustments to the reagent valves 16a through 16d and pulp level valves 18a

through 18d are made by an operator; otherwise the processes are similar. Additionally, manual control of the process was also compared as to experienced and inexperienced operators. As can be seen from Figure 2, manual control of the process by an experienced operator produces a more uniform metallurgy than control by an inexperienced operator. Computer control of the process obviates the need for an experienced operator as a uniform metallurgy was attained during the total test period. It should also be noted that the tailing stream 26 is more difficult to control within prescribed limits due to a low sensitivity; and manual control, even with experienced operators, tends to produce a stream having many upsets.

Other similar tests comparing computer control and manual control show that the average metallurgy using computer control more closely approximated the specified targets and also that the amplitude of swings above and below the targets was significantly reduced. Typical results are shown hereinbelow in Table II.

TABLE II

Stream	Target (%)	Computer Control		Manual Control	
		Average % Nickel	% Time Within Target Range	Average % Nickel	% Time Within Target Range
Primary Concentrate	8.75±0.5	8.67	85	8.21	60
Tailing	0.11±0.01	0.107	70	0.126	60

As a further example of the benefits to be derived from computer control (versus manual control) of the flotation process as contemplated herein, statistical results over a period of months show that higher primary concentrate grades (9.67% versus 8.21%) and lower tailing grades (0.110% versus 0.138%) were obtained. This, coupled with increased control

of the process, has resulted in a substantial direct economic return of higher metal recoveries, higher manpower efficiency (tons/man-shift) and lower operating costs because cell level rather than reagent addition was used to control the flotation process,frother consumption has been reduced about 35%. Aside from direct economic benefit, other intangible benefits such as operator education and a better understanding of the process have also been realized.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A froth flotation process for treating an ore pulp to recover a mineral-containing concentrate having a first predetermined composition and spent ore having a second predetermined composition, wherein said pulp is fed to a first flotation unit, a first product constituting said concentrate is recovered as froth from said first unit, tailing from said first unit is fed into a second flotation unit from which a second product is recovered as froth and said spent ore is recovered as tailing, each of said first and second units having means for adjusting the pulp level in said unit, and wherein the improvement comprises controlling said process by monitoring the weight of ore being fed into said first unit, adjusting addition of flotation reagents in response to said monitored weight, and performing the following sequence of steps:

i) determining the composition of said first product;

ii) determining the composition of said spent ore;

iii) generating, in accordance with a predetermined mathematical formula, correction signals responsive to the deviation of said first product composition from said first predetermined value and the deviation of said spent ore composition from said second predetermined value;

iv) applying said correction signals to said pulp level adjusting means; and

v) repeating Steps (i) to (iv) at regular time intervals throughout the process.

2. A process as claimed in claim 1 wherein each unit comprises a plurality of flotation cells connected in series, the tailing of an upstream cell constituting the feed for the successive cell, the combined froths from the cells of each unit constituting said first and second products.

3. A process as claimed in claim 2 wherein said Step (iv) comprises applying to said first unit cells said correction signal responsive to deviation of said first product composition from said first predetermined value, and applying to said second unit cells said correction signal responsive to deviation of said spent ore composition from said second predetermined value.

4. A process as claimed in claim 3 wherein input signals are generated indicative of said weight of ore, determined first product composition, determined spent ore composition and pulp levels in said cells; said signals are supplied to a digital computer programmed with said mathematical formula, a mathematical correlation of ore weight with flotation reagent additions and said predetermined values; and said computer generates said correction signals in accordance with said formula and reagent adjustment signals in accordance with said correlation.

5. A process as claimed in claim 4 wherein said formula is represented by the equation:

$$L = K_g (X_n - X_{n-1}) + K_g I (X_n - X_{sp})$$

where:

L is the change in pulp level at the n^{th} sampling interval expressed as a percentage of the full scale range of said pulp level adjusting means:

X_n is the first product or spent ore composition at the n^{th} sampling interval;

X_{n-1} is the first product or spent ore composition at the $(n-1)^{th}$ sampling interval;

K_g and I are proportional and integral gains, respectively:

$$K_g = 0\text{-}10$$
$$I = 0.1\text{-}20$$

6. A process as claimed in claim 4 wherein said input signals indicative of said determined first product and spent ore compositions are generated by an on-stream X-ray fluorescence analyzer.

7. A process as claimed in claim 4 wherein said computer causes an alert-message to be printed when said signal indicative of determined spent ore composition reaches a predetermined threshold.

8. A process as claimed in claim 4 wherein said time interval is about 3 minutes.

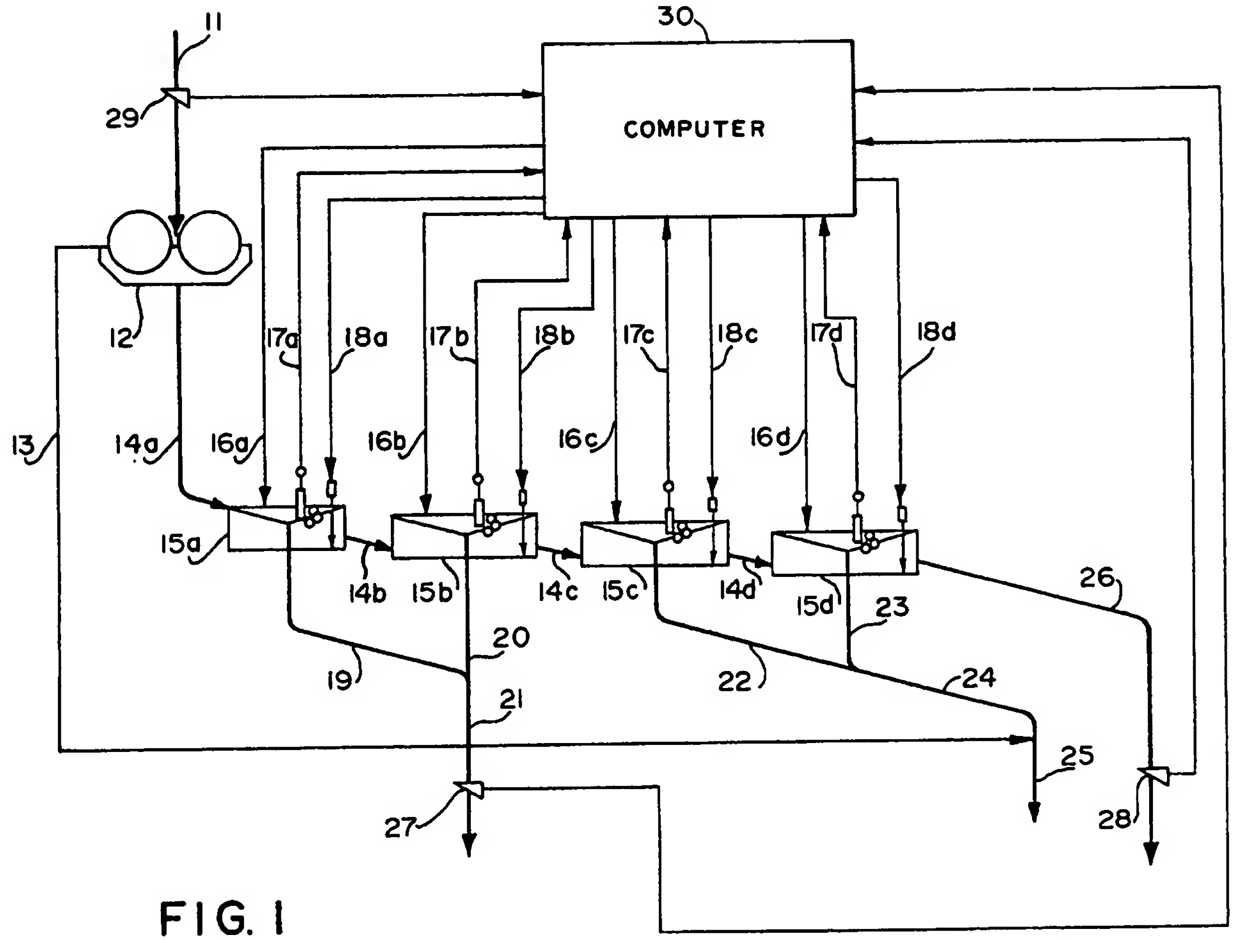

FIG. 1

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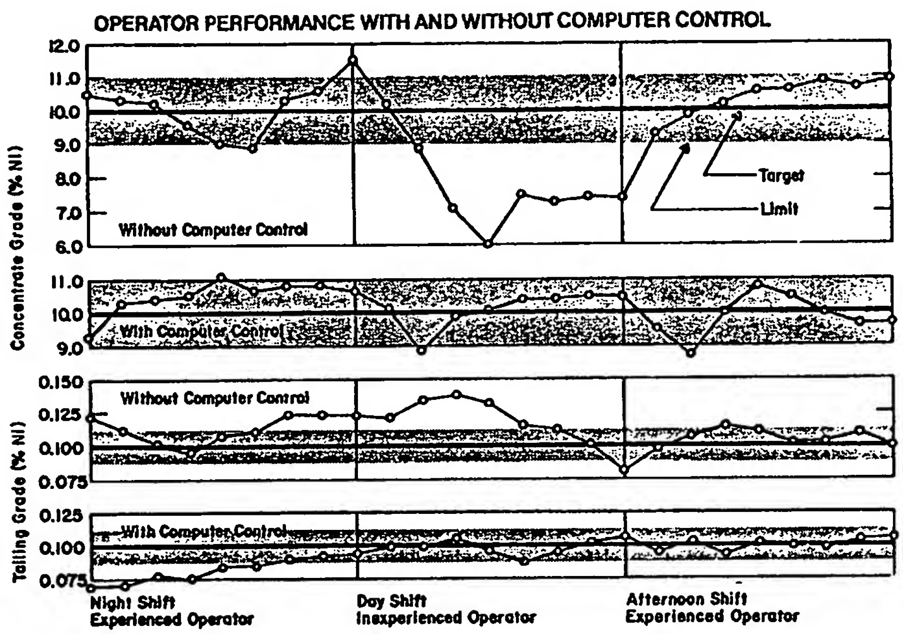

FIG. 2

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